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Sinderby et al.

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(54) **DETECTION OF DYNAMIC HYPERINFLATION IN SPONTANEOUSLY BREATHING MECHANICALLY VENTILATED PATIENTS**

(75) Inventors: **Christer Sinderby**, Toronto (CA); **Jennifer Beck**, Toronto (CA); **Norman Comtois**, Scarborough (CA); **Giacomo Grasselli**, Milan (IT)

(73) Assignee: **ST. MICHAEL'S HOSPITAL**, Toronto, Ontario (CA)

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(51) **Int. Cl.**

A61M 16/00 (2006.01)
A61B 5/091 (2006.01)

(52) **U.S. Cl.**

CPC ***A61M 16/0051*** (2013.01); ***A61B 5/091*** (2013.01); ***A61M 16/0003*** (2014.02); *A61M 2016/003* (2013.01); *A61M 2016/0036* (2013.01)

(58) **Field of Classification Search**

CPC A61M 16/00; A61M 16/0003; A61M 16/0051; A61M 2016/0027; A61M 2016/003; A61M 2016/0033; A61M 2016/0036

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,693,256 A 9/1987 Talonn
5,456,264 A * 10/1995 Series et al. 600/538

(Continued)

FOREIGN PATENT DOCUMENTS

WO	97/22377	6/1997
WO	2006/012205	2/2006
WO	2006/127573	11/2006

OTHER PUBLICATIONS

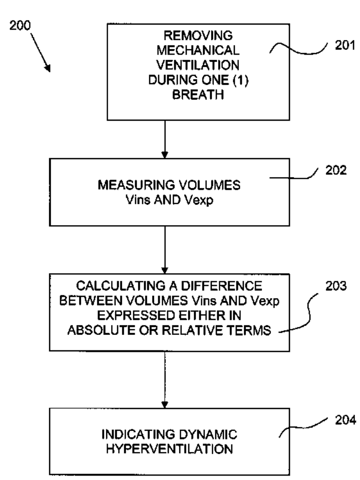
Blanch et al. "Measurement of Air Trapping, Intrinsic Positive End-in Expiratory Pressure, and Dynamic Hyperinflation in Mechanically Ventilated Patients", *Respiratory Care*, Jan. 2005, vol. 50, No. 1, pp. 110-124.

Primary Examiner — Justine Yu
Assistant Examiner — Colin W Stuart
(74) *Attorney, Agent, or Firm* — Fay Kaplun & Marcin, LLP

(57) **ABSTRACT**

A method and device for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient, wherein mechanical ventilation is removed during one breath of the patient, inspiratory and expiratory volumes of the patient are measured during the one breath, and a difference between the inspiratory and expiratory volumes measured during the one breath is calculated. Dynamic hyperinflation of the patient's lungs is indicated in relation to the calculated difference.

19 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2003/0226565	A1	12/2003	Sinderby et al.	
2005/0211246	A1	9/2005	Beck et al.	
2005/0284476	A1*	12/2005	Blanch et al.	128/204.21
2006/0206036	A1	9/2006	Quinn	
2007/0049843	A1*	3/2007	Derchak	600/538
2007/0142742	A1	6/2007	Aljuri et al.	

* cited by examiner

FIGURE 1

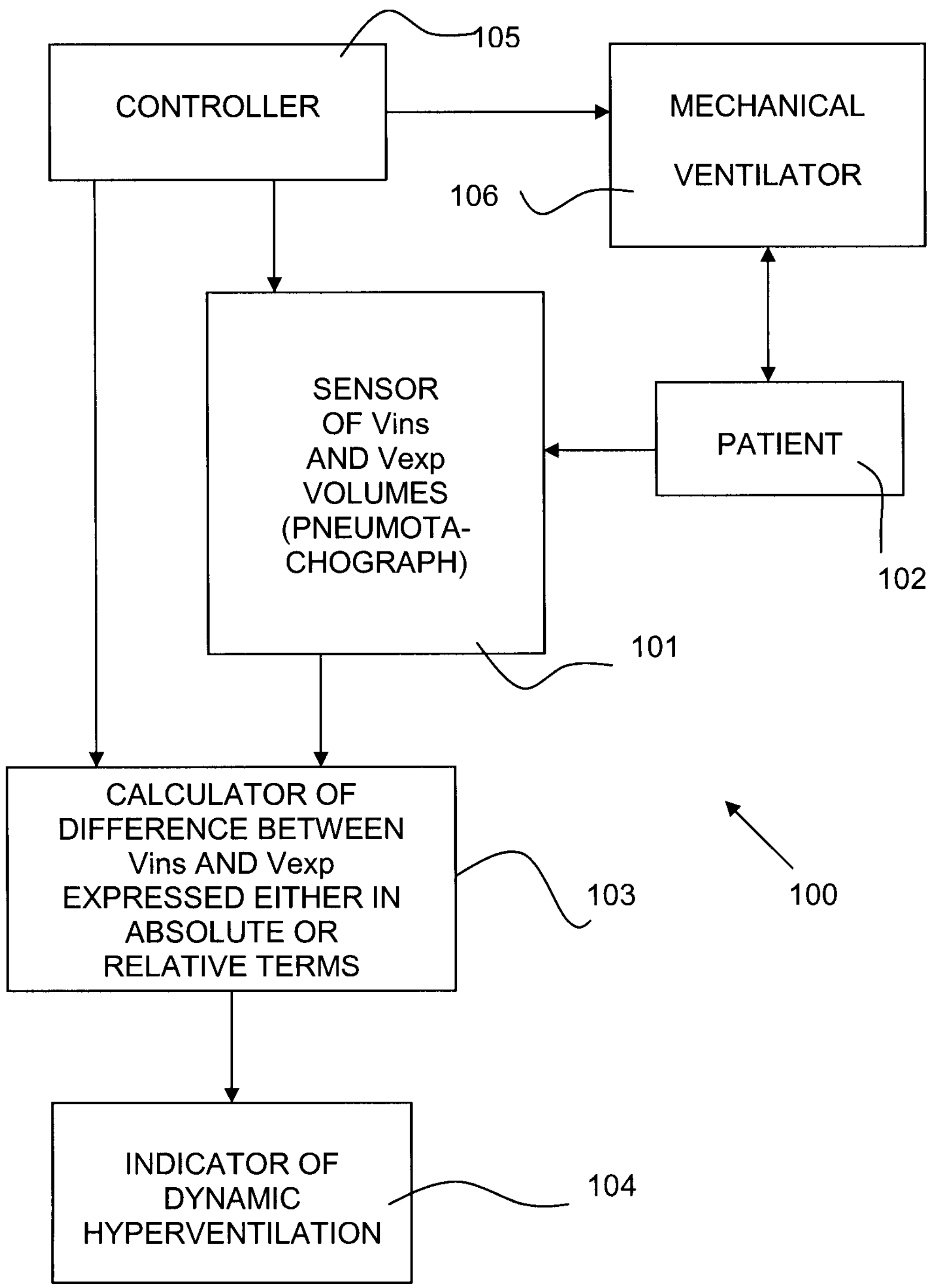
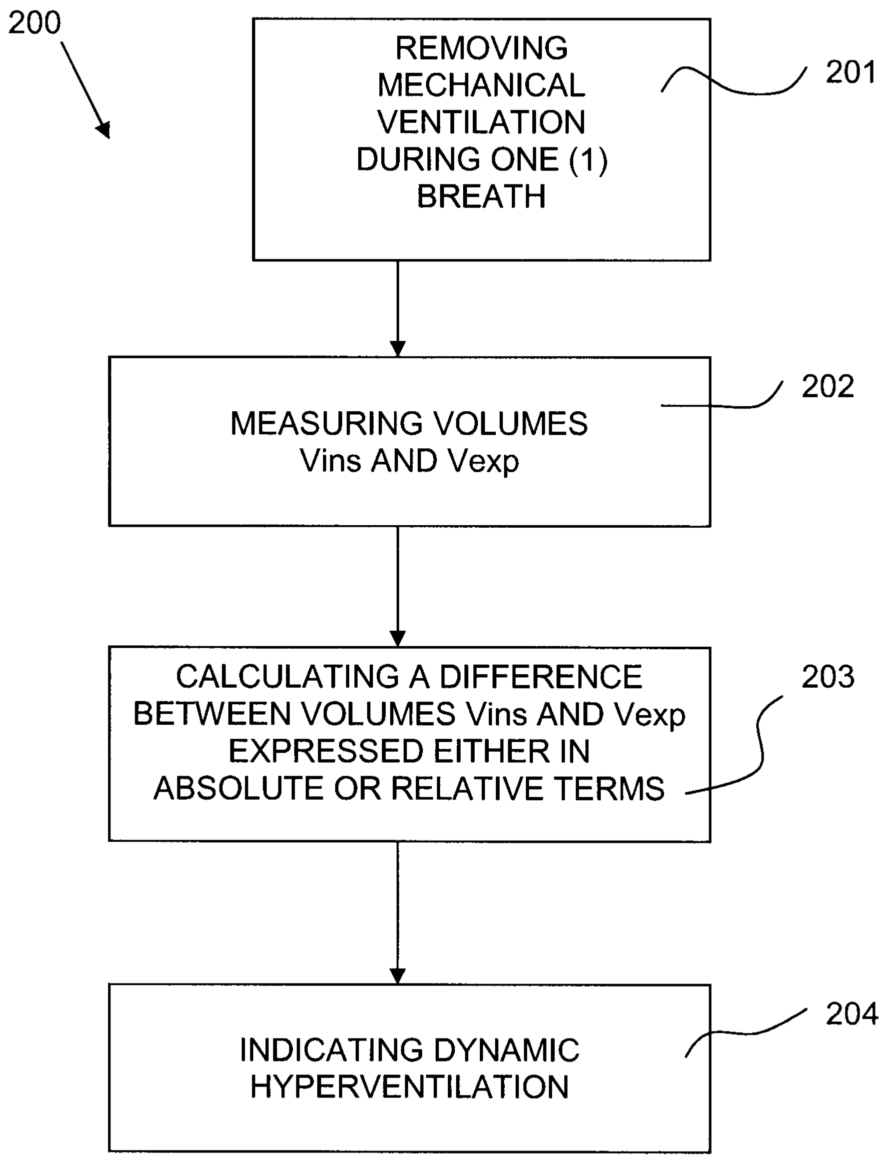

CONTROLLER
105
MECHANICAL
VENTILATOR
106
SENSOR
OF Vins
AND Vexp
VOLUMES
(PNEUMOTA-
CHOGRAPH)
PATIENT
102
101
CALCULATOR OF
DIFFERENCE BETWEEN
Vins AND Vexp
EXPRESSED EITHER IN
ABSOLUTE OR
RELATIVE TERMS
103
100
INDICATOR OF
DYNAMIC
HYPERVENTILATION
104

FIGURE 2


200
REMOVING MECHANICAL VENTILATION DURING ONE (1) BREATH
201
MEASURING VOLUMES Vins AND Vexp
202
CALCULATING A DIFFERENCE BETWEEN VOLUMES Vins AND Vexp EXPRESSED EITHER IN ABSOLUTE OR RELATIVE TERMS
203
INDICATING DYNAMIC HYPERVENTILATION
204

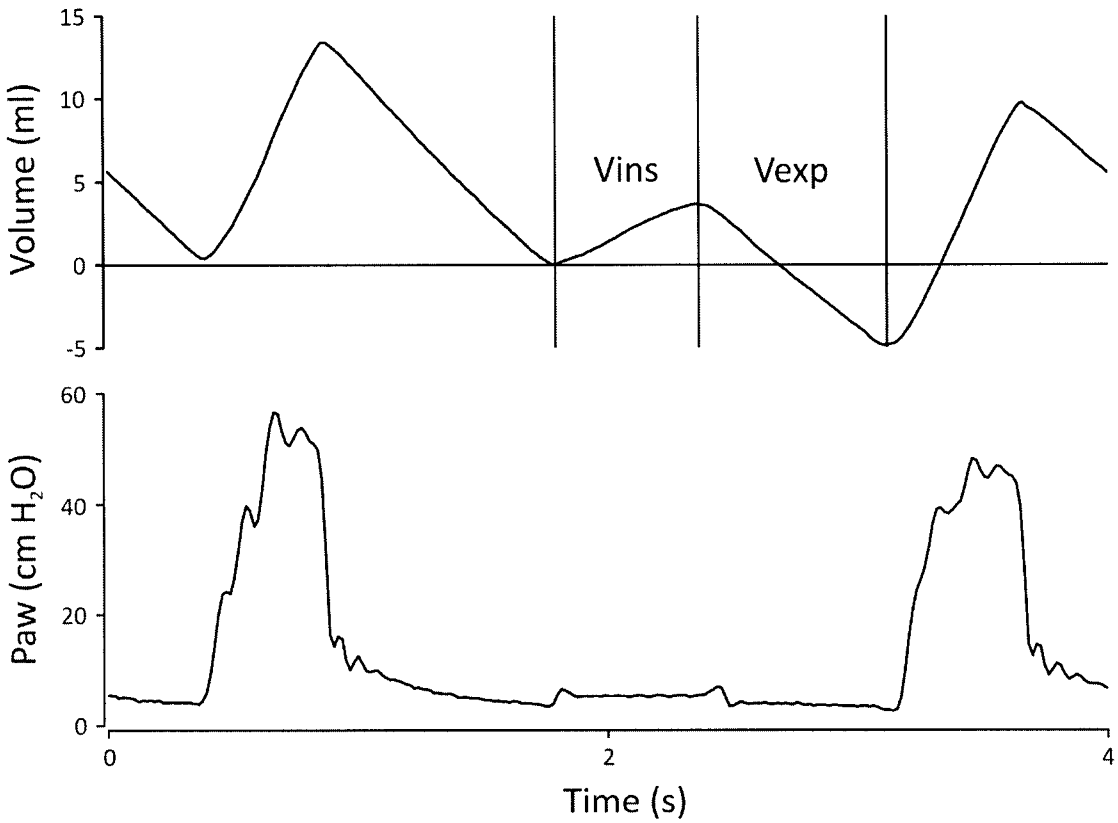
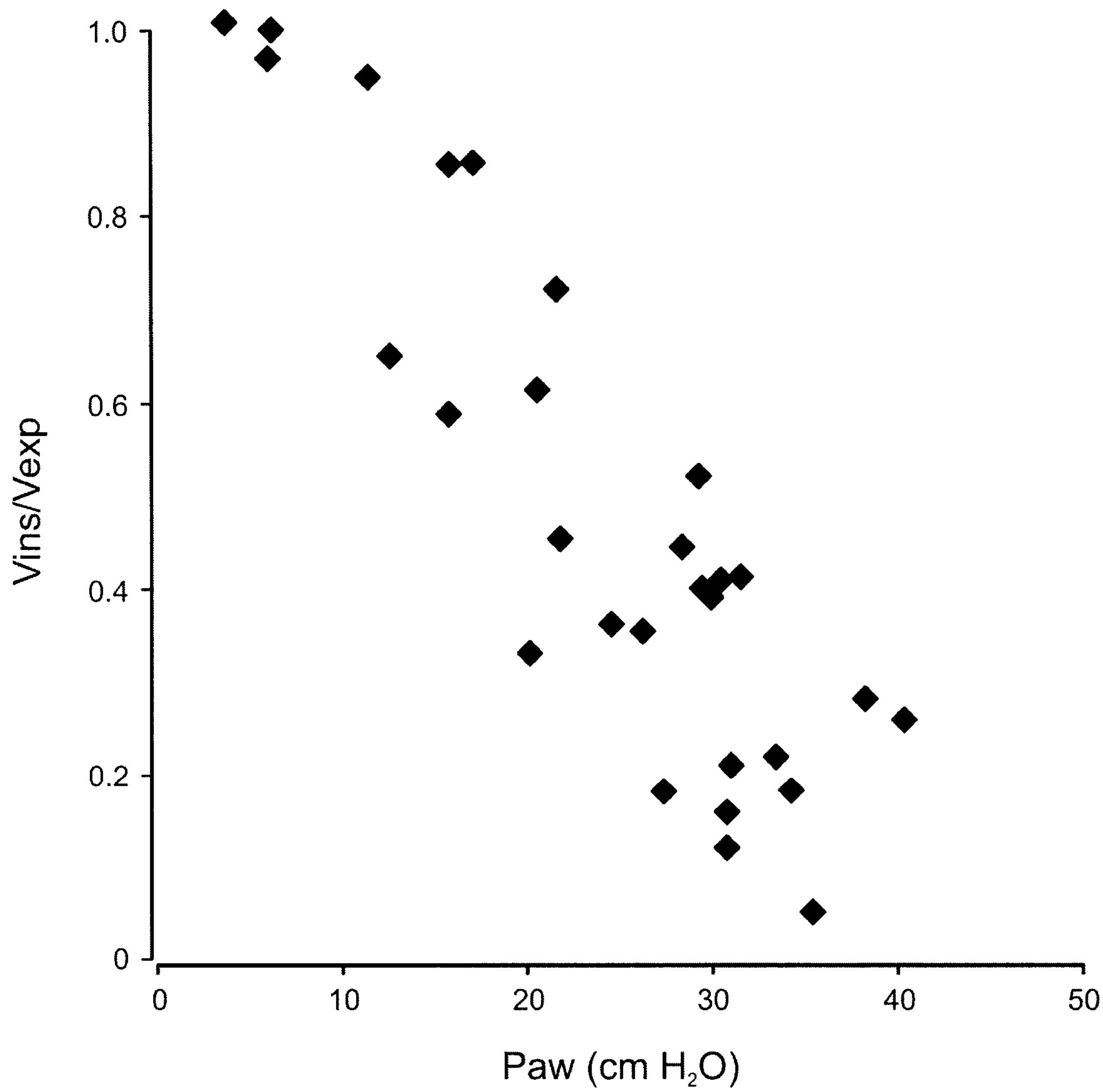


Figure 3

Figure 4



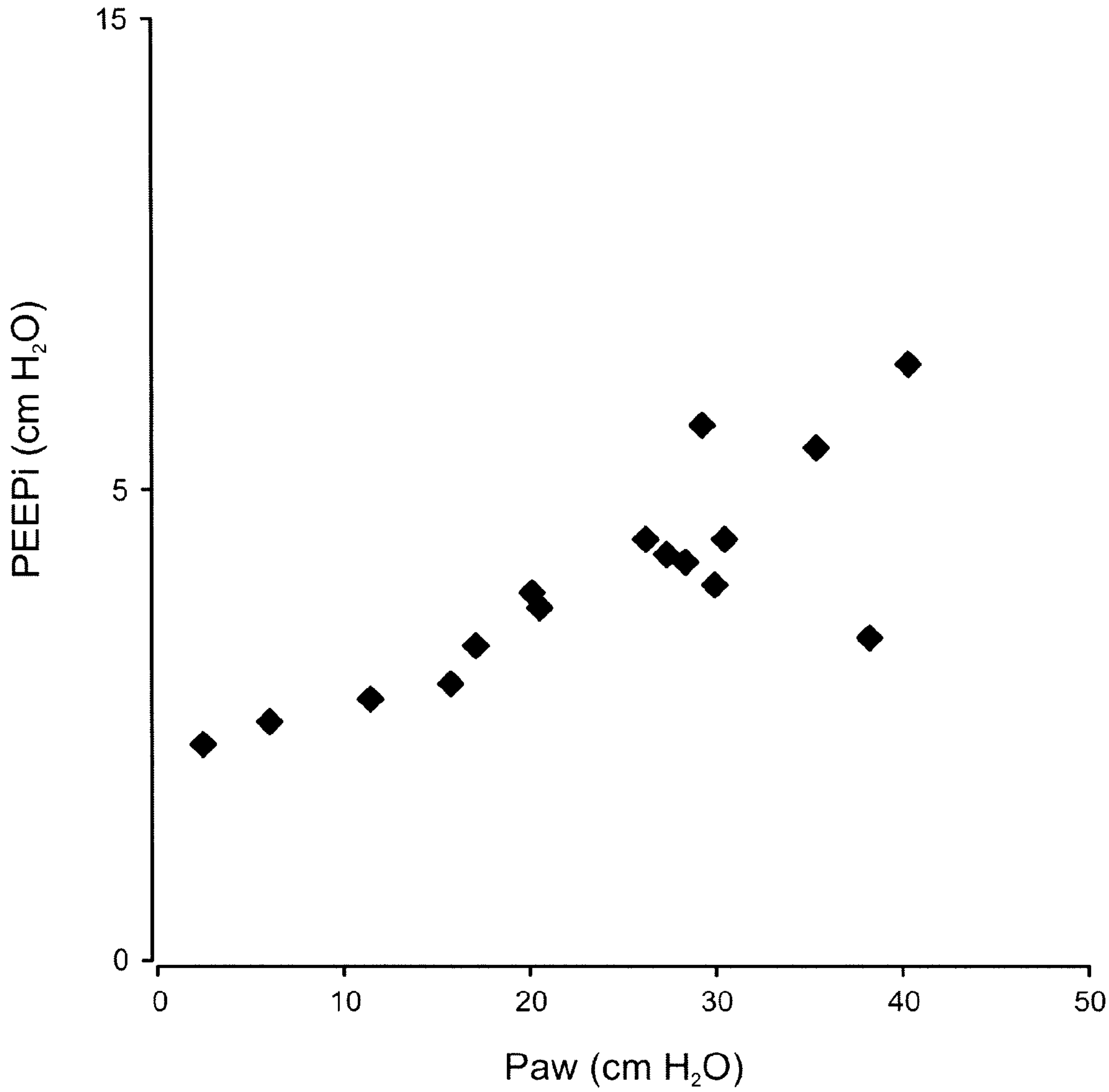


Figure 5

DETECTION OF DYNAMIC HYPERINFLATION IN SPONTANEOUSLY BREATHING MECHANICALLY VENTILATED PATIENTS

FIELD

The present invention relates to a method and device for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient.

BACKGROUND

Intrinsic positive end-expiratory pressure (intrinsic PEEP or PEEPi) is a phenomena occurring due to insufficient expiratory time, preventing the lungs of a patient from becoming sufficiently emptied at the end of expiration, trapping air in the lungs, and increasing the end-expiratory lung volume (dynamic hyperinflation).

During mechanical ventilation of a patient, the presence of dynamic hyperinflation and intrinsic PEEP (PEEPi) can be aggravated by high levels of mechanical ventilation and trigger/off-cycling settings on the mechanical ventilator.

Clinical methods to detect/quantify intrinsic PEEP (PEEPi) comprise measuring pressures at an opening of mechanically ventilating airways during occlusions of those airways; such methods are difficult to interpret during spontaneous breathing.

SUMMARY

According to a first aspect of the invention, there is provided a method for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient, comprising: removing mechanical ventilation during one breath of the patient; measuring inspiratory and expiratory volumes of the patient during said one breath; calculating a difference between the inspiratory and expiratory volumes measured during said one breath; and indicating dynamic hyperinflation of the patient's lungs in relation to the calculated difference.

According to a second aspect of the invention, there is provided a device for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient, comprising: a controller for removing mechanical ventilation during one breath of the patient; a sensor of inspiratory and expiratory volumes of the patient during said one breath; a calculator of a difference between the inspiratory and expiratory volumes sensed during said one breath; and an indicator of dynamic hyperinflation of the patient's lungs in relation to the calculated difference.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present invention will become apparent from reading of the following non restrictive description of an illustrative embodiment thereof, given by way of example only with reference to the accompanying drawings in which:

FIG. **1** is a schematic block diagram of a device for determining dynamic hyperinflation during mechanical ventilation of a patient;

FIG. **2** is a flow chart of a method for determining dynamic hyperinflation during mechanical ventilation of a patient;

FIG. **3** are graphs showing volume and airway pressure (Paw) over time during breaths of a mechanically ventilated patient and during breaths of a non-mechanically ventilated patient;

FIG. **4** is a graph showing how the ratio Inspiratory Volume (Vins)/Expiratory Volume (Vexp) of a patient decreases during increasing levels of mechanical ventilation (airway pressure Paw) when breathing against a high inspiratory and expiratory resistive load; and

FIG. **5** is a graph showing how values of intrinsic PEEP or PEEPi increases during increasing levels of mechanical ventilation (airway pressure Paw) when the patient breathes against a high inspiratory and expiratory resistive load; the graph of FIG. **5** results from the same recordings as the graph of FIG. **4**.

DETAILED DESCRIPTION

As described hereinabove, the concept of air-trapping relates to a quantity of air penetrating the lungs of a patient larger than the quantity of air leaving the patient's lungs. Air-trapping induced by mechanical ventilation actually worsens contractility of the inspiratory muscles due to dynamic hyperinflation until a level where weakness of the inspiratory muscles and added mechanical ventilation reach an equilibrium causing inspiratory (Vins) and expiratory (Vexp) volumes to match.

When mechanical ventilation is removed in the presence of air-trapping, the patient has difficulty to inhale due to lost mechanical ventilation and weak inspiratory muscles. However, due to extra stored energy i.e. increased elastic recoil in the inspiratory muscles due to air-trapping, the patient has no difficulty to generate force to exhale.

Accordingly, air-trapping during mechanical ventilation should hence result in similar inspiratory (Vins) and expiratory (Vexp) volumes during breaths with mechanical ventilation, whereas inspiratory volumes (Vins) are smaller than expiratory volumes (Vexp) during the first breaths after mechanical ventilation has been removed. When the lungs are not trapping air, the inspiratory (Vins) and expiratory (Vexp) volumes should be similar for breaths both with mechanical ventilation and without mechanical ventilation. With these concepts in mind, FIG. **1** of the appended drawings illustrates a device **100** for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient.

The device **100** of FIG. **1** comprises a sensor **101** of inspiratory (Vins) and expiratory (Vexp) volumes of a patient **102**. As a non-limitative example, the sensor **101** may comprise a pneumotachograph or any other suitable sensor. The sensor **101** is connected to the patient's airways to detect the inspiratory (Vins) and expiratory (Vexp) volumes.

A calculator **103** is responsive to the inspiratory (Vins) and expiratory (Vexp) volumes detected by the sensor **101** to calculate a difference between the detected inspiratory (Vins) and expiratory (Vexp) volumes of the patient.

An indicator **104** is responsive to the difference between the detected inspiratory (Vins) and expiratory (Vexp) volumes of the patient, for example the ratio Vins/Vexp, to indicate dynamic hyperinflation.

A controller **105** is connected to the sensor **101**, the calculator **103** and a mechanical ventilator **106** providing mechanical ventilation to the patient **102**.

A method **200** (FIG. **2**) for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient using the device of FIG. **1** will now be described with reference both to FIGS. **1** and **2**.

Operation **201** (FIG. **2**)

The controller **105** (FIG. **1**) controls the mechanical ventilator **106** (FIG. **1**) to remove mechanical ventilation of the patient **102** (FIG. **1**) during one (1) breath of the patient **102** (FIG. **1**).

Operation **202** (FIG. **2**)

The controller **105** (FIG. **1**) controls the sensor **101** (FIG. **1**), for example a pneumotachograph, to measure:

the volume (Inspiratory volume Vins) inhaled by the patient **102** (FIG. **1**) during the one (1) breath during which mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) is removed; and

the volume (Expiratory volume Vexp) exhaled by the patient **102** (FIG. **1**) during the one (1) breath during which mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) is removed.

For that purpose, the sensor **101** (FIG. **1**) is connected to the airways of the patient **102** (FIG. **1**).

Operation **203** (FIG. **2**)

The controller **105** (FIG. **1**) also commands the calculator **103** (FIG. **1**) to calculate a difference between the inspiratory volume (Vins) and the expiratory volume (Vexp) as measured by the sensor **101** (FIG. **1**) during the one (1) breath during which mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) is removed. The calculated difference can be expressed either in absolute (for example a mathematical difference between Vins and Vexp) or relative (for example a ratio between Vins and Vexp) terms.

More specifically, for the one (1) breath without mechanical ventilation from the mechanical ventilator **106** (FIG. **1**), the calculator **103** calculates the difference between the inspiratory volume (Vins) and the expiratory volume (Vexp) as measured by the sensor **101** (FIG. **1**), for example a ratio (Vins/Vexp) between these inspiratory (Vins) and expiratory (Vexp) volumes as measured by the sensor **101** during the one (1) breath during which mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) is removed.

If the ratio (Vins/Vexp) is close to 1 this suggests that the patient **102** is able to exhale the same amount of air as was inhaled during the one (1) breath without mechanical ventilation, suggesting that air-trapping due to the mechanical ventilator **106** (FIG. **1**) does not have a major impact and that dynamic hyperinflation induced by mechanical ventilation is not present.

However, if the ratio (Vins/Vexp) becomes close to 0, this indicates that the patient **102** (FIG. **1**) has considerable problems related to inspiration relative to expiration and that the mechanical ventilator **102** (FIG. **1**) induces air-trapping in the lungs of the patient **102** (FIG. **1**) and therefore dynamic hyperinflation.

Operation **204** (FIG. **2**)

An indicator **104** (FIG. **1**) is responsive to the ratio (Vins/Vexp) from the calculator **103** (FIG. **1**) to indicate dynamic hyperinflation of the patient.

For example, the indicator **104** (FIG. **1**) may produce a light signal going from e.g. green if the ratio (Vins/Vexp) is close to 1 to indicate that dynamic hyperinflation is not present and change towards e.g. red if the ratio (Vins/Vexp) is close to 0 to indicate that dynamic hyperinflation is present.

Also, the ratio (Vins/Vexp) could be used to guide conventional titration of external PEEP, or in combination with previous neural PEEP titration methods (US Published Patent Applications 2005/0211246 and 2003/0226565).

FIG. **3** represents graphs showing volume and airway pressure (Paw) over time during breaths with mechanical ventilation and breaths without mechanical ventilation. An example of segments where inspiratory (Vins) and expiratory (Vexp) volumes are measured during the one (1) breath during which mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) is removed, are indicated by vertical lines. As shown by the bottom curve of FIG. **3**, the mechanical ventilator **106** is controlled by the controller **105** to maintain a level of positive pressure (PEEP) in the patient's airways during the one (1) breath during which mechanical ventilation from the mechanical ventilator **106** is removed.

In the graph of FIG. **4**, the points show how the ratio (Vins/Vexp) decreases with increasing levels of mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) when the patient **102** breathes against a high inspiratory and expiratory resistive load.

In the graph of FIG. **5**, the points show how conventional PEEPi values increase with increasing levels of mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) when the patient **102** breathes against a high inspiratory and expiratory resistive load (same recordings as in FIG. **4**).

The sensor **101** (FIG. **1**), for example a pneumotachograph, may measure during operation **202** the inspiratory volume (Vins) and the expiratory volume (Vexp) during a plurality of successive or non successive singles breaths during which mechanical ventilation of the patient **102** (FIG. **1**) by the mechanical ventilator **106** (FIG. **1**) is removed. The calculator **103** (FIG. **1**) then compute the ratio (Vins/Vexp) for example as an average of the ratios (Vins/Vexp) calculated from the inspiratory (Vins) and expiratory (Vexp) volumes measured by the sensor **101** during the respective single breaths without mechanical ventilation.

Also, the above described method **200** (FIG. **2**) for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient can be implemented at any given level of mechanical ventilation delivered by the mechanical ventilator **106** (FIG. **1**) in any type of mechanical ventilation mode.

What is claimed is:

1. A method for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient, comprising:

removing, using a controller, mechanical ventilation during one breath of the patient;

measuring inspiratory and expiratory volumes of the patient during said one breath;

calculating, using a calculator, a difference between the inspiratory and expiratory volumes measured during said one breath, the calculated difference having a value; and

indicating, using an indicator, presence or absence of dynamic hyperinflation of the patient's lungs on the basis of a position of the value of the calculated difference with respect to a first value indicative of presence of dynamic hyperinflation and a second value indicative of absence of dynamic hyperinflation.

2. A method for determining dynamic hyperinflation as defined in claim **1**, wherein measuring the inspiratory volume comprises measuring a volume inhaled by the patient during said one breath during which mechanical ventilation is removed.

3. A method for determining dynamic hyperinflation as defined in claim **1**, wherein measuring the expiratory volume comprises measuring a volume exhaled by the patient during said one breath during which mechanical ventilation is removed.

4. A method for determining dynamic hyperinflation as defined in claim **1**, wherein calculating the difference comprises calculating a ratio between the inspiratory and expiratory volumes measured during said one breath.

5. A method for determining dynamic hyperinflation as defined in claim **1**, wherein calculating the difference comprises calculating a ratio Vins/Vexp between the inspiratory volume Vins and the expiratory volume Vexp measured during said one breath.

6. A method for determining dynamic hyperinflation as defined in claim **5**, wherein the first value is 0 and the second value is 1, and wherein indicating dynamic hyperinflation comprises indicating that dynamic hyperinflation is absent when the ratio Vins/Vexp is close to 1 and indicating that dynamic hyperinflation is present when the ratio Vins/Vexp is close to 0.

7. A method for determining dynamic hyperinflation as defined in claim **1**, wherein said one breath comprise a plurality of successive or non successive single breaths during which mechanical ventilation of the patient is removed.

8. A method for determining dynamic hyperinflation as defined in claim **7**, wherein measuring the inspiratory and expiratory volumes comprise measuring the inspiratory and expiratory volumes during said plurality of single breaths, and wherein calculating the difference comprises calculating a ratio Vins/Vexp from the inspiratory volumes Vins and the expiratory volumes Vexp measured during said plurality of single breaths.

9. A method for determining dynamic hyperinflation as defined in claim **1**, wherein removing mechanical ventilation during one breath of the patient comprises maintaining a level of positive pressure in the patient's airways during said one breath.

10. A device for determining dynamic hyperinflation during mechanical ventilation of a spontaneously breathing patient, comprising:

a controller for removing mechanical ventilation during one breath of the patient;

a sensor of inspiratory and expiratory volumes of the patient during said one breath;

a calculator of a difference between the inspiratory and expiratory volumes sensed during said one breath, the calculated difference having a value; and

an indicator of presence or absence of dynamic hyperinflation of the patient's lungs on the basis of a position of the value of the calculated difference with respect to a first value indicative of presence of dynamic hyperinflation and a second value indicative of absence of dynamic hyperinflation.

11. A device for determining dynamic hyperinflation as defined in claim **10**, wherein the sensor is adapted to be connected to patient's airways to measure as the inspiratory volume a volume inhaled by the patient during said one breath during which mechanical ventilation is removed.

12. A device for determining dynamic hyperinflation as defined in claim **10**, wherein the sensor is adapted to be connected to patient's airways to measure as the expiratory volume a volume exhaled by the patient during said one breath during which mechanical ventilation is removed.

13. A device for determining dynamic hyperinflation as defined in claim **10**, wherein the calculator of the difference calculates a ratio between the inspiratory and expiratory volumes measured during said one breath.

14. A device for determining dynamic hyperinflation as defined in claim **10**, wherein the calculator of the difference calculates a ratio Vins/Vexp between the inspiratory volume Vins and the expiratory volume Vexp measured during said one breath.

15. A device for determining dynamic hyperinflation as defined in claim **14**, wherein the first value is 0 and the second value is 1, and wherein the indicator indicates that dynamic hyperinflation is absent when the ratio Vins/Vexp is close to 1 and indicates that dynamic hyperinflation is present when the ratio Vins/Vexp is close to 0.

16. A device for determining dynamic hyperinflation as defined in claim **10**, Wherein said one breath comprise a plurality of successive or non successive single breaths during which mechanical ventilation of the patient is removed.

17. A device for determining dynamic hyperinflation as defined in claim **16**, wherein the sensor measures the inspiratory and expiratory volumes during said plurality of single breaths, and wherein the calculator of the difference calculates a ratio Vins/Vexp from the inspiratory volumes Vins and the expiratory volumes Vexp measured during the plurality of single breaths.

18. A device for determining dynamic hyperinflation as defined in claim **10**, wherein the controller is connected to:

a mechanical ventilator providing mechanical ventilation of the patient to control the mechanical ventilator to remove the mechanical ventilation during said one breath;

the sensor of inspiratory and expiratory volumes to control said sensor to measure the inspiratory and expiratory volumes during said one breath; and

the calculator of the difference to control said calculator to calculate the difference between the inspiratory and expiratory volumes measured during said one breath.

19. A device for determining dynamic hyperinflation as defined in claim **10**, wherein the controller controls the removal of mechanical ventilation during said one breath of the patient to maintain a level of positive pressure in the patient's airways during said one breath.

* * * * *